Spatial and Temporal Variability of Grain Size and Small-Scale Mophology

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LONG-TERM GOALS

We will test the hypothesis that heterogeneity of coastal subaerial and subaqueous morphology on many scales is correlated with heterogeneity in surface sediments, which influences the morphodynamic feedback.

OBJECTIVES

The specific objectives of this work are to:

- develop and integrate a suite of sensors for efficiently measuring surf zone morphodynamics and hydrodynamics, in particular surface sediment grain size distribution within the surf zone,
- obtain, modify, and evaluate an amphibious surf zone crawler as a platform for nearshore observations,
- test the sensors in the field and obtain measurements of the temporal and spatial variability of sediments and bedforms
- investigate heterogeneity of morphology in the context of the local sedimentological and hydrodynamic conditions.

APPROACH

Historically, it has been assumed by most nearshore models that beaches are uniform in grain size and relative smooth. Recent studies have found that this is not the case. Ripples and megaripples are observed to be ubiquitous (Nielsen 1981, Gallagher et al. 2003, amoung many others) and to depend on grain size (Ardhuin et al. 2002, Trembanis et al. 2004), cross-shore sand bar migration is better modeled when small changes in grain size are considered (Gallagher et al. 1998), grain size is observed to vary in and around beah cusps, rip current systems, rippled scour depressions and erosional hot spots (eg, Komar 1973, MacMahan et al. 2005, Murray and Thieler 2004, McNinch 2004). Here we hypothesize that heterogeneity of coastal seafloor morphology on many scales is correlated with

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heterogeneity in surface sediments, which influence the morphodynamic evolution. We are making measurements to test this hypothesis.

To test this hypothesis, detailed measurements of grain size, morphology and the hydrodynamic forcing environment are needed. Unfortunately measuring grain size is traditionally tedious and time consuming. As part of this study we are developing a digital imaging system (DIS) for measuring grain size following the work of Rubin (2004). From the auto-correlation of digital images, information about the surface grain size distribution can be obtained quickly and inexpensively. Thus, the DIS will be used to make high spatial- and temporal-resolution surveys of grain size.

The first goal of this work is to develop a versitile suite of sensors, which measures grain size (using the newly developed DIS), small scale bed morphology and bathymetry (from a sonar array, a pressure sensor and KGPS), sediment suspension profiles (from an acoustic backscatter system), water properties (conductivity and temperature sensor and transmissometer), and current profiles (using a vertical array of 6 electromagntic current meters). The second goal is to place the instruments on an autonomous crawler that will operate within the surf zone. The instruments will be integrated using a National Instruments field programmable gate array for robust and independent data acquisition. This efficient measuring system will be deployed easily in many environments including the nearshore. The third goal of this study is to test this suite of instruments in the field. A field test utilizing the crawler is planned for the spring 2007 in Monterey, CA.

WORK COMPLETED

During this second year of the project significant progress has been made on the development of the digital imaging system (DIS). In May, 2005, we participated in a field experiment in England with the University of Plymouth, where the DIS was tested alongside traditional sediment measurements. The results of laboratory and field tests of the instrument were presented at AGU Ocean Sciences in Honolulu in Feb 2006 and are discussed below. In May 2006, we participated in a field experiment in France with the Univeristy of Plymouth and the University of Bordeaux, with the intention of correcting mistakes from the first experiment and refining the technique. The results from this experiment are being analyzed at this time and will be presented at AGU Fall Meeting in Dec 2006 in San Francisco.

In addition, progress has been made with the crawler system. The crawler is an existing system modified for surf zone operation. The crawler was received in February, but required replacement motors, delaying the construction and evaluation of the system. Thus, the crawler itself is still in the hands of the manufacturer who is working on the motor modifications and will be finished in October 2006. The remainder of the instruments have been purchased and the control and data acquisition system for the crawler is being programmed by Jeff Brown, a graduate student at UD. Thus progress is being made, but there are no scientific results to be reported at this time.

RESULTS

The prototype DIS consists of a 5 megapixel, digital, Nikon D70 camera (purchased with a grant from Franklin and Marshall's faculty development fund), a macro lens with magnifiers, and an Ikelite underwater housing. The light and focus are fixed so the system is easy to handle and control by a diver, where the diver simply presses the plexiglass lens of the housing against the sand and obtains uniform images. Following Rubin's (2004) technique, auto-correlation is run on a digital image and the correlation curve is compared quantitatively (via linear least-squares regression or interpolation) to correlation curves used for calibration to determine the sediment grain size and distribution. The calibration curves are generated by photographing sieved sand from the same location. The calibration process is time-consuming and makes the technique valuable only when many images are planned for high-resolution sedimentological surveys.

The DIS was taken to Sennen, Cornwall, England in May to participate in a cross-shore sediment transport experiment being conducted by colleagues at the University of Plymouth (they contributed some travel money for this project). Univ. Plym. was making measurements of waves, currents, sediment transport, bed changes, ripples and sediment grain size (via traditional sample collection for laboratory analysis). A sample natural image from Sennen is shown in Fig 1 (left) and its corresponding autocorrelation curve (asterisks) and the required calibration curves are shown in Fig 1 (right). Mean grain size is estimated from the curves in Fig 1 by interpolating the points on the natural curve between the calibration curves at each pixel offset and then averaging. The grain size distribution can be estimated by calculating a non-negative least squares fit of the natural curve to the calibration curves. This gives an estimate of the percentage of each calibration curves that is contained in the natural curve.

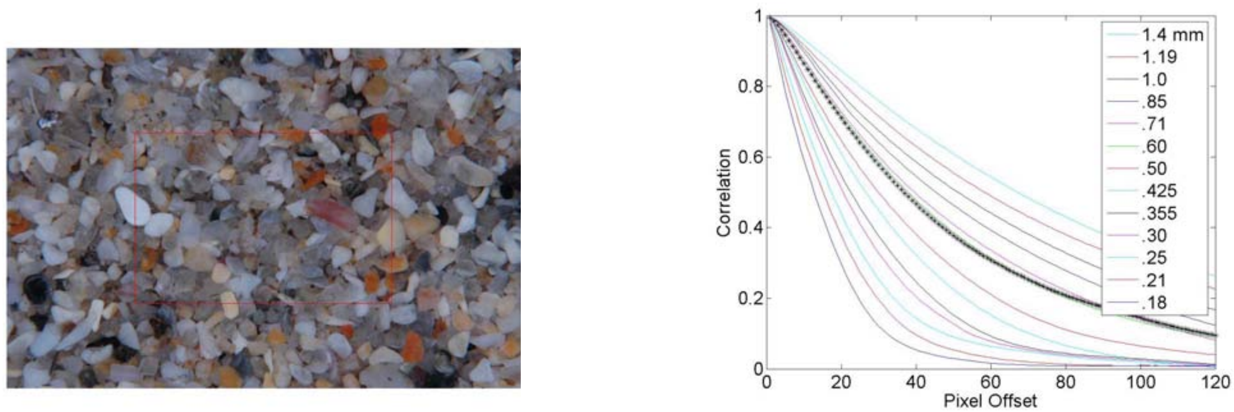

Figure 1. Example image of natural sand sample from Sennen, England (left panel). The red square represents the sub-image which is analyzed. Right panel: autocorrelation curve (asterisks) from image on left and calibration curves (thin lines) corresponding to different sieved fractions. [Correlation curves fall off from a value of 1 at 0 pixel offset to close to 0 for large pixel offsets. Curves for largest grains fall off slowly, curves for smallest grains fall off quickly. The natural curve, being a combination of all grains, falls off at an intermediate rate.]

Estimates of sediment distribution are shown in Fig 2, where the thin dotted lines represent sediment distribution estimated from different individual photos of the same sample. When all estimates are averaged, the distribution from the DIS (blue) is quite close to that from sieving (black). The mean grain sizes from the two techniques are also similar (vertical lines). Rubin (2004) found that the autocorrelation technique was very reliable in estimating mean grain size.

The macrotidal beach at Sennen is morphologically interesting with beach cusps at the top of a coarse, steep forshore and a broad low tide terrace where megaripples are frequently observed. These features were all sampled and this opportune data set seemed ideal to test both the DIS and the underlying scientific hypothesis. Thus, large 2-D surveys were done with GPS, the DIS, and traditional sediment sampling. The mean grains size estimated from the DIS for one of the larger scale surveys is shown in

Fig 3 along with the measured morphology. Unfortunately, the quality of the data collected turned out to be low for three reasons. First, three photos were taken at each location and we have found subsequently in the laboratory that more photographs are needed to generate a stable estimate of both mean grain size and distribution (thin dotted lines in Fig 2 are from individual photographs and are highly variable, but if many of these are averaged a stable estimate of distribution is obtained). Second, air bubbles and puddling of water in the intermediate, wet/dry, intertidal area biased the results of the autocorrelation. Third, the focus was slightly off in some images owing to the short depth of field with macro photography and poor focus also generates bias in the results of the autocorrelation. Bubbles and/or bad focus required the exclusion of many of the photographs and thus reduced the number of samples we had at each location (sometimes to nothing). Because of this, the data presented in Fig 3 are not reliable. However, they are included to show that the variability of grain size on the beach at Sennen is large (between 0.3 and 0.7 mm) and to show that the DIS has the potential to create extremely interesting pictures of grain size variability.

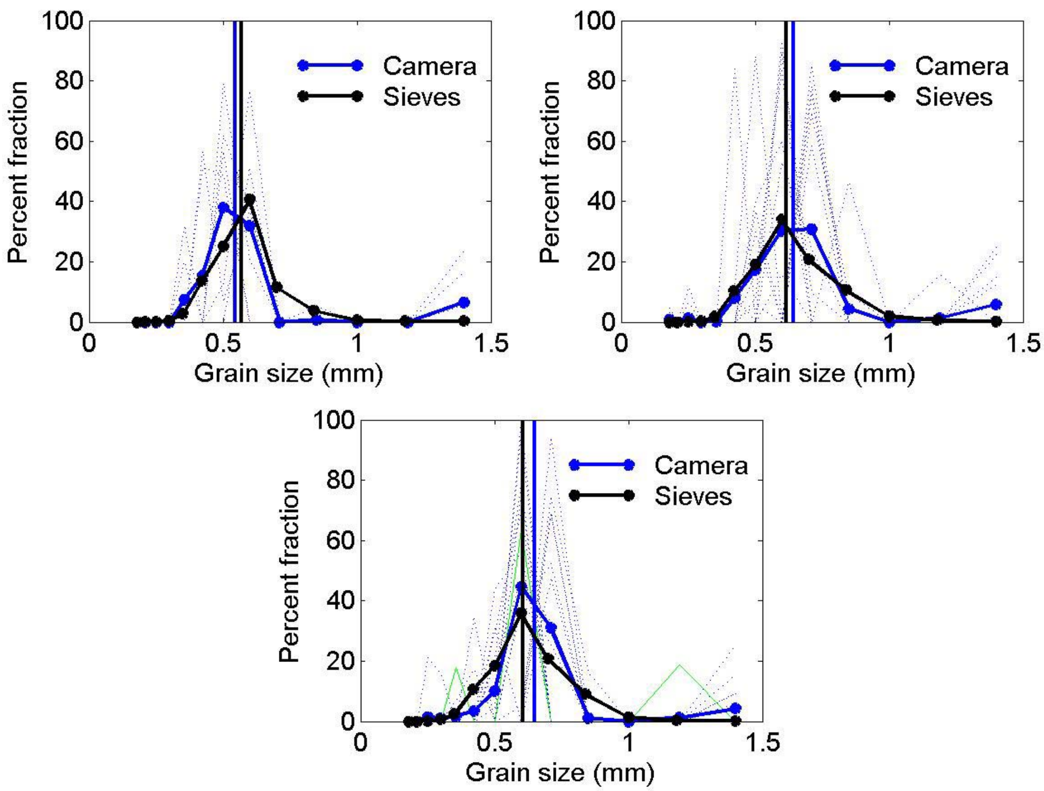

Figure 2. Three examples of mean grain size (vertical lines) and grain size distribution (lines with symbols) from samples collected at Sennen and brought back to the lab for comparison. Blue lines are estimated from the camera system (DIS) and the black lines are measured with sieves. The thin dotted lines are distributions estimated from individual photographs, the thick blue line with circles is the mean of all the thin lines. The thin green line in the bottom panel is the distribution from the photograph in Fig 1. [In all panels, the distributions are unimodal and approximately gaussian and the two measurement techniques agree well and show a mean grain size and a peak in the distribution between 0.5 and 0.7 mm]

Data were collected at Truc Vert, France in May 2006 and particular attention was paid to getting the focus sharp and 5-7 photographs were sampled at each location. Thus the problems discussed above have been corrected. These data are being analyzed at this time and will be presented at the AGU Fall Meeting in Dec 2006. The findings from this instrument development study (including results from the laboratory studies, Sennen and Truc Vert) will be prepared for publication in the next few months.

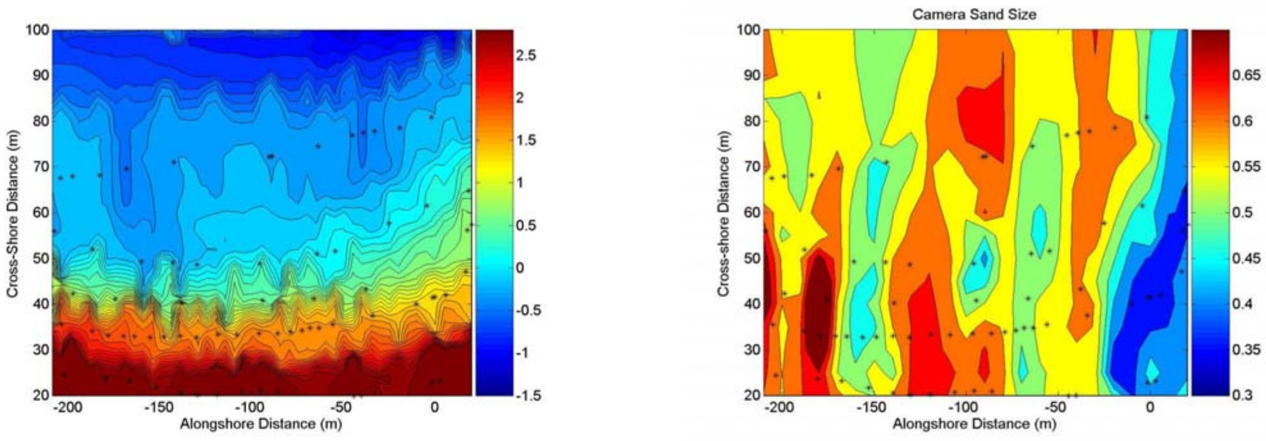

Fig 3. Left panel shows the morphology measured at Sennen (with the color axis in m) using a DGPS system on May 18. The steep forshore slope with beach cusps is visible at the bottom of the panel and the broad intertidal shoal is seen between about 50 and 80 m in the cross shore. The right panel shows grain size estimated with the DIS (with the color axis in mm). The asterisks represent the DIS sample locastions. Although the left and right panels are not highly correlated (see text), the grain size variability on this beach is large (0.3- 0.7 mm).

IMPACT/APPLICATION

Understanding the morphodynamics of sedimentary environments is important for recreational, economic, and military reasons. This work will help to shed light on the importance of grain size on sediment transport and will help elucidate whether variations in grain size are important to or even drive changes in morphology in many coastal environments. In addition, the development of a suite of instruments on an amphibious crawler has the potential to revolutionize measurement in the coastal zone.

RELATED PROJECTS

This work also is being supported by an ONR DURIP award to Dr. MacMahan at University of Delaware.

Inexpensive DGPS drifters
An inexpensive (<$150) off-the-shelf hand-held Global Positioning System (GPS) that internally records the raw pseudo-ranges and phase-carrier information was evaluated for absolute position and velocity estimates for measuring oceanographic currents [re-submitted for publication and presented at ICCE 2006]. Simple modifications were required to improve the position accuracy, including reducing antenna signal multi-pathing, isolating the internal antenna to avoid position averaging, and using survey-grade differential GPS post-processing software. The standard deviation for kinematic positions

for stationary and dynamic surveys was O(0.1m), depending upon satellite coverage. The speed errors on land relative to a survey-grade differential GPS system were O(0.01m/s). The hand-held GPS was mounted on a surf zone drifter and evaluated in the field. The Lagrangian GPS derived velocities were correlated with in situ Eulerian velocities within the surf zone in the alongshore, but were not correlated in the cross-shore, a problem related to drifter design not GPS response. Evaluation of drifter design is currently being performed in University of Delaware wave-current flume and will be presented at the AGU Fall Meeting in San Francisco. Owing to the low cost and small size of the hand-held GPS, a large number of systems can be deployed for absolute position tracking and velocity estimates for oceanographic drifters.

Very Low Frequency Surfzone Motions
Nearshore observations of velocity fluctuations in the frequency band $0.0005<f<0.004$Hz (periods 4-30 min) were described, and compared with numerical simulations (in preparation for submission to JGR, Fall 2006). Analysis of coherent bi-axial electromagnetic current meters from the Sandyduck experiment show that these very low frequency (VLF) velocity fluctuations are most energetic in the vortical (non-gravity wave) region of frequency-alongshore-wavenumber (*f-ky*) space. Cases with strong mean alongshore currents and subsequent significant shear instability contributions to vortical VLF motions are excluded. The energy of VLF pressure fluctuations is much smaller than the energy of the corresponding velocity fluctuations. VLF energy increases with increasing wave height, and decays rapidly seawards of the surfzone. The largest observed root-mean-squared VLF velocity fluctuations were about 18 cm/s occurring when *Hrms* =1.25m in 8m water depth. The numerical simulations are based on the linearized response to non-linear short-wave forcing using the linear shallow-water equations, and include roller contributions, bottom friction, and radiation-stress forcing. The magnitude of the modeled and observed velocity fluctuations are correlated (R^2=0.49, m=1.34 in the surf zone, R^2=0.45, m=0.43 outside of the surf zone). Energy distributions in *f-ky* space are qualitatively similar. Modeled and observed VLF energy decreases as $1=f^2$. Wave refraction limits the alongshore spacing of VLF energy peaks to $ky < 0.012m^{-1}$. Accelerations in VLF velocity fluctuations are balanced by bottom shear stress and gradients in wave forcing and pressure. Numerical simulations suggest that VLF motions are driven by nonlinear interactions between directionally-spread swell and sea (0.04-0.3Hz) waves.

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Abstracts and Presentations

Gallagher, E.L., J. MacMahan, P. Russell, G. Masselink, Morphological Variability and Grain Size from Digital Images. Abstract submitted to the AGU Fall Meeting, San Francisco, Dec 2006.

Gallagher, E.L., J. MacMahan, P. Russell, G. Masselink, N. Auger. Grain Size from Digital Images and Morphological Variability. Presented at the AGU Ocean Sciences Meeting, February 2006.

Gallagher, E.L., The Eyeball: Estimating Sand Grain Size With Digital Images. Invited presentation, Woods Hole Oceanographic Institution, July 15, 2005.

Gallagher, E.L., The Eyeball: Estimating Sand Grain Size With Digital Images. Invited presentation, University of Delaware, September 27, 2005.

MacMahan, J., Field Observations of Rip Currents (RIPEX). Invited Presentation, Alabama Sea Grant, May, 2006.

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MacMahan, J., A. Reniers, R. Guza, E. Thornton, and S. Elgar, Very low frequency surf zone motions. Presented at the AGU Ocean Sciences Meeting, February 2006.

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Reniers, A., J. MacMahan, and E. Thornton, Wave-current interaction in modeling nearshore morphodynamics. Presented at the AGU Ocean Sciences Meeting, February 2006.

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